

# PHEV Advanced Series Gen-Set Development/ Demonstration Activity

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# Overview

## Timeline

- Start – FY2012
- Finish – FY2014
- 40% complete

## Budget

- Total project funding
  - DOE current share – 100%
  - FY14 cost share– 50%
- Funding for FY12: \$ 200K
- Funding for FY13: \$ 200K

## Barriers

- Electric vehicle customer acceptance:
  - Alleviate range anxiety
  - Reduce costs thru smaller ESS size
  - Reduce charging infrastructure impact
- Petroleum displacement
  - Improve component and system efficiency

## Partners

- ORNL's FEERC and PEEMRC groups
- MAHLE Powertrain
- Remy International

**MAHLE**

*Powertrain*



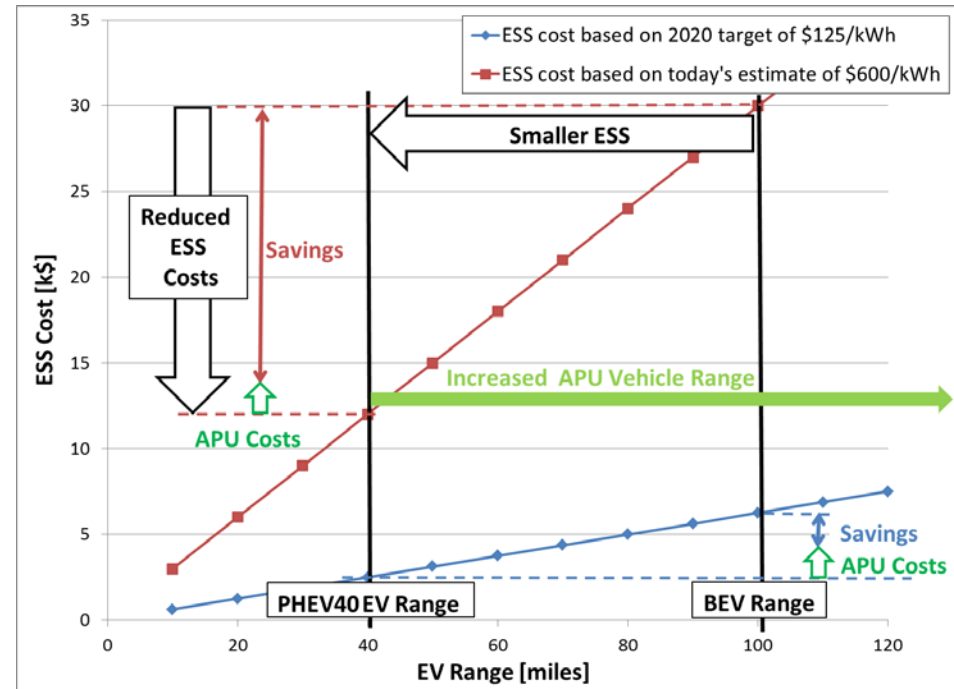
# Project Objective

- **Overall Objective**

- Optimize engine-generator system for Range Extender Electric Vehicle applications: improve efficiency while minimizing cost and packaging penalties.

- **FY13 Objectives**

- Down-select engine/fuel and generator/power electronics technologies
- Update system component models and analyze benefit scenarios
- Pursue partnerships to proceed with hardware integration of IC engine and electric machine



# Milestones

Date	Milestones and Go/No-Go Decisions	Status
Sept-2012	<u>Milestone</u> : Identify potential technologies, simulate engine-generator combinations at the vehicle level	Completed
Sept-2012	<u>Go/No-Go decision</u> : Determine from simulation study which technologies to test and integrate in genset	Completed
Jan-2013	<u>Milestone</u> : Establish partnerships to proceed with hardware integration of IC engine and electric machine	Completed
Sept-2013	<u>Milestone</u> : Finalize component selection and sourcing based on technical merit and partnerships	On Track
Sept-2013	<u>Go/No-Go decision</u> : Are partnerships in place and component hardware available?	

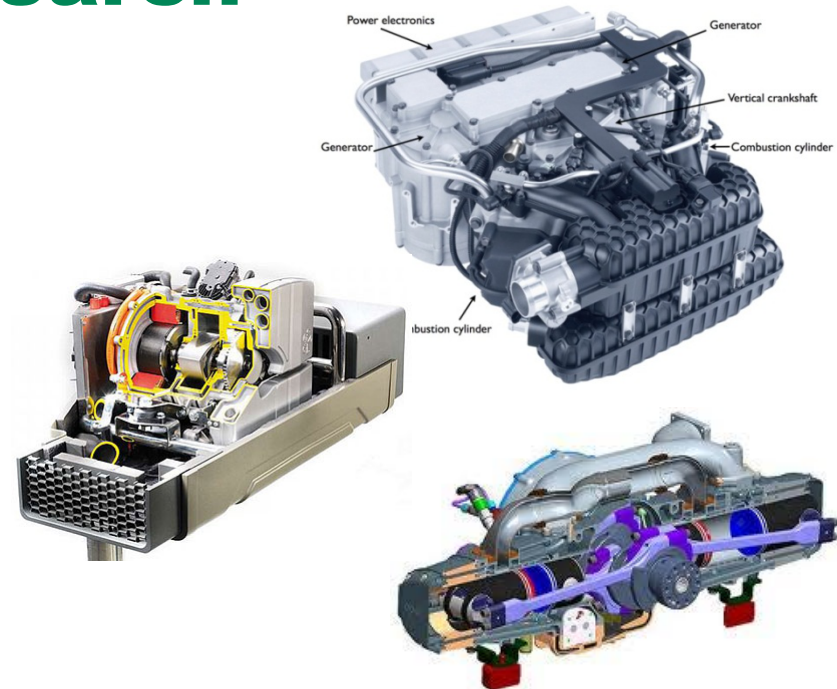
# Approach/Strategy

- Literature search
  - Survey state-of-the-art technology and commercially-off-the-shelf technologies
- Simulation study
  - Down-select set of technologies: engine and generator
  - Evaluate technologies benefits at vehicle level
- Partnerships creation
  - Draw from expertise, capabilities and past projects at ORNL's Fuels, Engines and Emissions group and Power Electronics and Electric Machinery group
  - Collaborate with industry to further existing technologies

# Technical Accomplishments

## Literature search

- Renewed interest for Range Extenders
- Most common technologies:
  - Conventional PFI gasoline engine: small displacement (<1.2l), low power (<35kW)
  - Permanent magnet motor
- Other technologies
  - Wankel engines
  - Opposed Piston Opposed Cylinder (OPOC) engines
  - Turbines
- Very little information on generators
- No production systems, just prototypes



	Power	Technology	Displacement	Cylinder	Generator
<b>Lotus</b>	35kW	4 stroke, PFI	1200cc	3	Not specified
<b>FEV-Pierburg</b>	30kW	4 stroke, PFI	800cc	2	Permanent magnet
<b>Mahle</b>	30kW	4 stroke, PFI	900cc	2	Axial flux generator
<b>Getrag</b>	14kW	4 stroke, PFI	1000cc	3	Not specified
<b>Polaris</b>	22kW	4 stroke, PFI	325cc	1	Not specified
<b>AVL</b>	15kW	Wankel	254cc	1	Permanent magnet
<b>FEV</b>	18kW	Wankel	295cc	1	Not specified
<b>AIXRO</b>	15kW	Wankel	294cc	1	Permanent magnet



# Technical Accomplishments Simulation Study

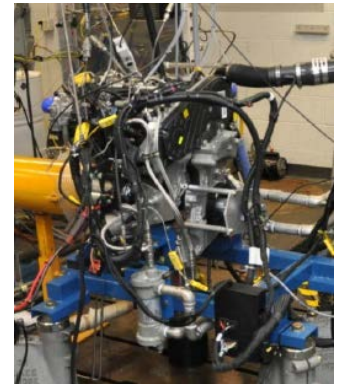
- The simulation study considered the following technologies:

- Engine types:

- Gasoline Port Fuel Injected (PFI)
- Gasoline Stoichiometric Direct Injection (GDI)
- Ethanol Direct Injection (EDI)
- Gasoline Homogenous Charge Compression Ignition (HCCI)
- Reactivity Controlled Compression Ignition (RCCI)
- Diesel

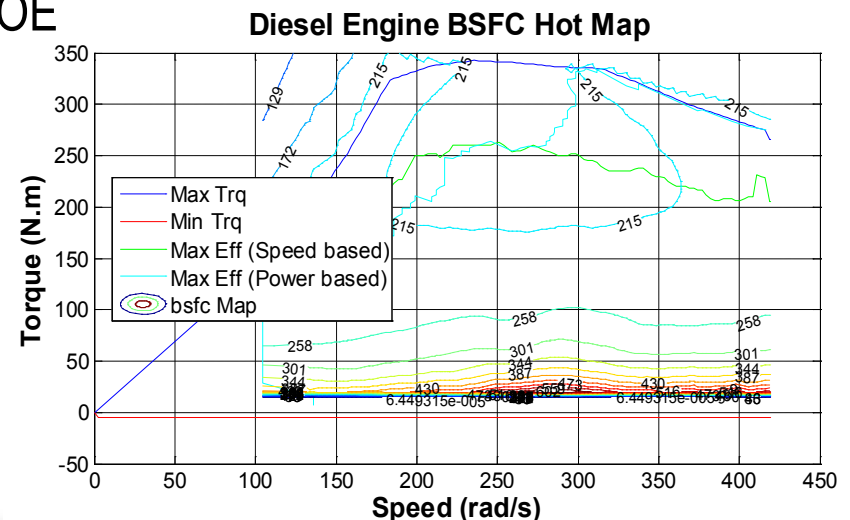
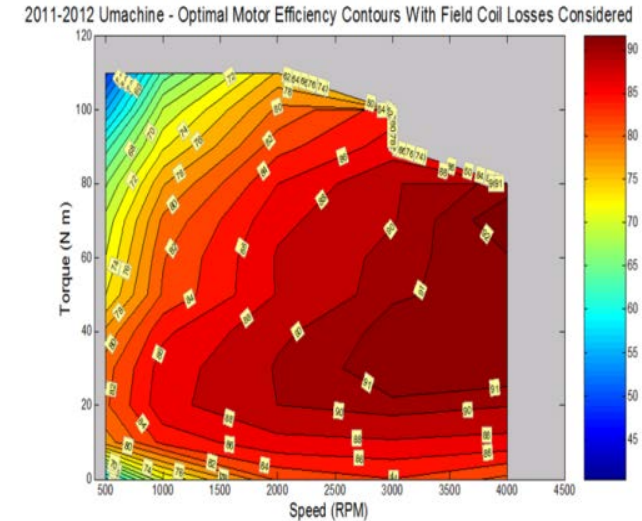
- Generator types

- Interior Permanent Magnet (IPM) machine
- Field Wound (FW) machine
- Induction Machine (IM)
- Switched Reluctance Machine (SRM)



# Technical Accomplishments Simulation Study

- Vehicle level simulation performed with Autonomie
- Some new generator and engine component models were created:
  - Autonomie look-up table models
  - Data extracted from steady state characterizations performed by FEERC and PEEMRC during previously completed DOE projects





# Technical Accomplishments

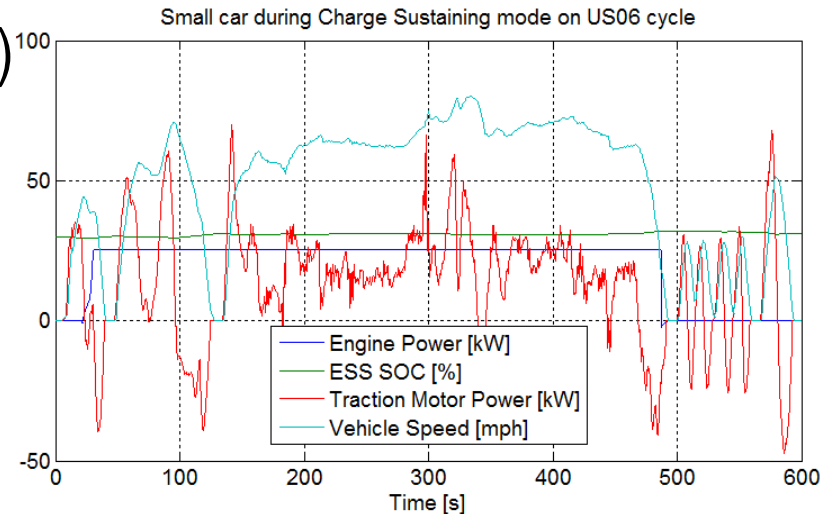
## Simulation Study

- Autonomie model of series PHEV passenger car (Nissan LEAF<sup>®</sup>-like size)

- Charge sustaining mode
- Thermostatic State Of Charge control
- Engine operating point based its peak efficiency

- Engine power output determination, 30kW is suitable to:

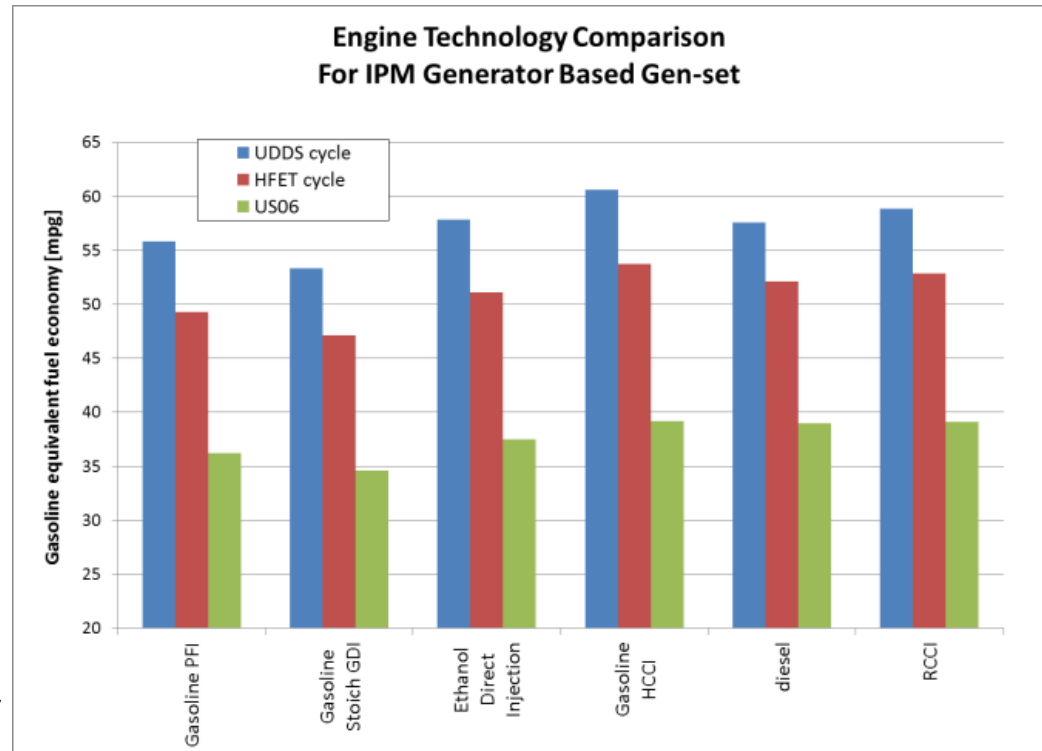
- Maintain ESS energy levels over US06 cycle
- Drive 70mph on a flat surface
- Drive 60mph on a 2% grade



Vehicle speed	Grade	Engine Power
[mph]	[%]	[kW]
60	0	18.7
70	0	26.0
80	0	36.3
60	2	28.9
60	4	39.2
60	6	50.0

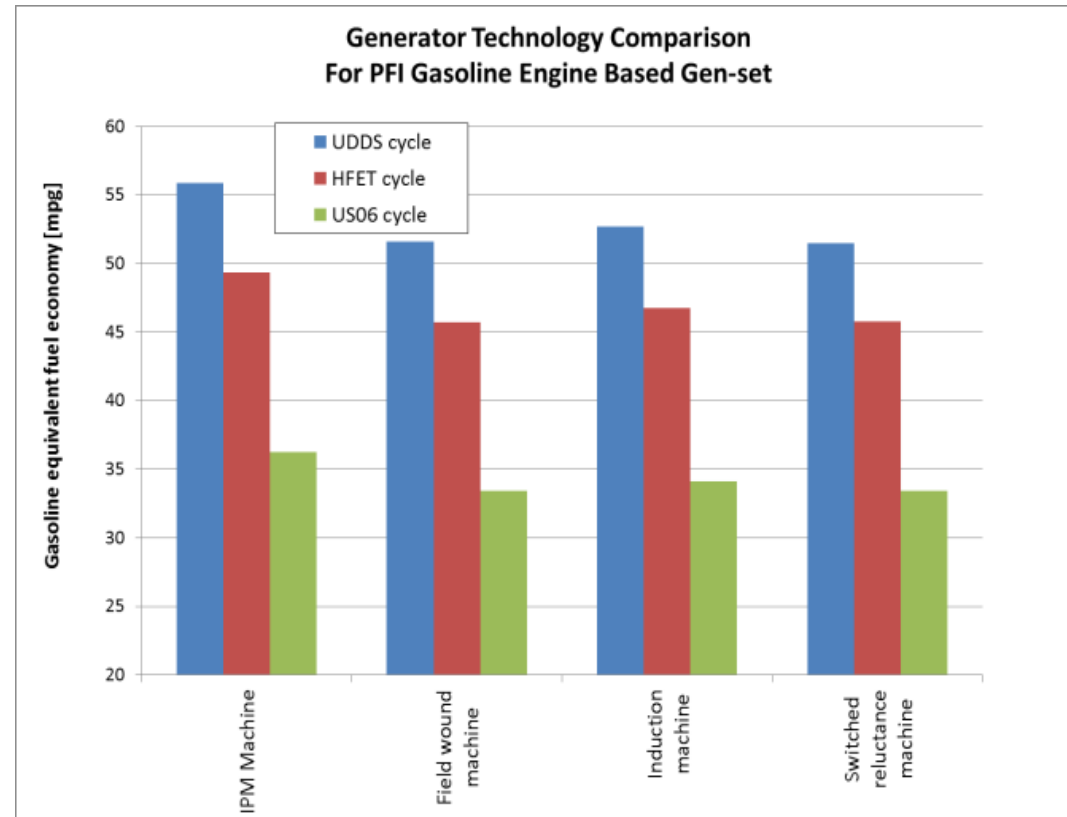
# Technical Accomplishments Simulation Study

- Engine technology analysis
  - HCCI proved to be the most efficient ahead of RCCI, Diesel, ethanol, PFI gasoline (Atkinson) and GDI
  - Because of after-treatment requirements and complexity, RCCI and Diesel are not considered for next phase
  - Next phase to investigate alternative fuels and advanced combustion applicable to industry partner base engine hardware.



# Technical Accomplishments Simulation Study

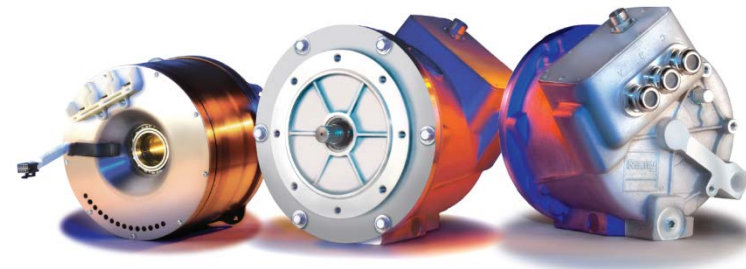
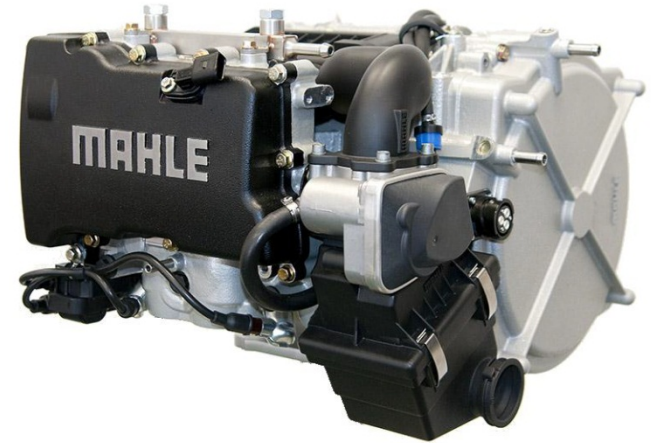
- Motor technology Analysis
  - Interior permanent magnet generator demonstrated the best fuel economy ahead of induction machine and wound field and switched reluctance machines
  - Next phase to investigate induction machines as the most efficient non-rare earth based technology





# Technical Accomplishments

## Partnerships Creation

- Engine technology partnerships
  - MAHLE has already developed a prototype PFI engine for a range extender application
  - Collaboration will involve use of alternate fuel for this engine and as well as combustion performance analysis
  - Paperwork (NDA, MTA and CRADA) in process
- Motor technology partnerships
  - ORNL PEEMRC group will be testing and optimizing an induction machine design provided by Remy.
  - Upon completion, that optimized machine will be used as the generator in our range extender testing



# Collaboration and Coordination

Organization	Type of Collaboration/Coordination
ORNL FEERC	Internal combustion engine expertise and testing
ORNL PEERMC	Electric machine expertise and testing
MAHLE Powertrain 	Internal combustion engine expertise, supply of engine and testing support
Remy International 	Electric machine expertise and supply of electric machine

# Proposed Future Work

- **Remainder of FY13**

- Finalize component selection and hardware deliverables with committed partners
- Refine simulation study based on actual data from partners
  - ICE base engine parameters received and integrated into model

- **FY14**

- Collaborate with MAHLE Powertrain to:
  - Test IC engine with alternative fuels: Ethanol and natural gas
  - Investigate MAHLE Turbulent Jet Ignition benefits on a range-extender application
- Expand ORNL PEEMRC testing of Remy's induction machine to include generator mode and transients
- Test MAHLE engine and Remy's machine as a range extender using Hardware-In-the-Loop test cell
- Optimize range extender as a system



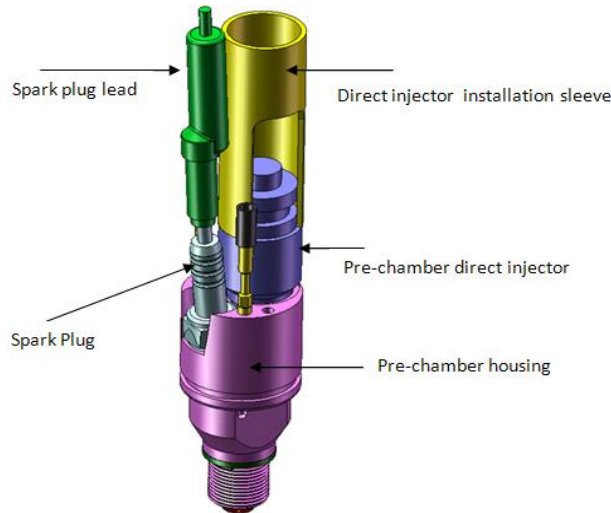
# Summary

- Relevance
  - Range anxiety, utility factor and cost of large Energy Storage Systems are 'real' road blocks to customer's acceptance of electric vehicles
  - Range Extender Electric Vehicles reduce overall oil consumption and offer a viable alternative to pure electric vehicles but they have to be cost effective and efficient as a system
- Approach
  - Identify component technologies and demonstrate system level genset optimization suitable for automotive range extender applications
- Technical accomplishments and progress
  - Technology selection through literature search and simulation study
    - Non rare earth electric machines : Induction machine
    - Alternative fuel PFI engine and other advanced engine technologies depending on partnership
  - Partnerships creation: MAHLE Powertrain and Remy International
- Collaborations:
  - Internal: ORNL FEERC and PEEMRC
  - External: MAHLE Powertrain and Remy International
- Proposed Future Work
  - Refine simulation, Finalize partnerships and proceed with hardware testing

# Technical Back-Up Slides

# MAHLE's Turbulent Jet Ignition

\*Specialists at MAHLE Powertrain have recently been developing a novel combustion system concept which offers significant fuel economy benefits without the need for expensive engine hardware.



MAHLE Powertrain's Turbulent Jet Ignition (TJI) utilizes a spark-initiated pre-chamber combustion process in an otherwise conventional gasoline engine to achieve fuel economy improvements of up to 20%. Engine-out NO<sub>x</sub> emissions are also virtually reduced to zero levels, negating the need for lean NO<sub>x</sub> after-treatment.

Existing jet ignition systems involve the creation of hot gas jets from a pre-chamber which are then introduced into the cylinder where they rapidly induce ignition of the main in-cylinder charge. MAHLE's TJI system is characterized by auxiliary pre-chamber fuelling, small orifices connecting the main and pre-chamber combustion cavities and a very small pre-chamber volume. The smaller orifice size causes turbulence in the hot gas jets which then penetrate deeper into the main combustion chamber and cause a distributed ignition effect. This process then allows extension of knock limits and increased compression ratios (up to 14:1) combined with lower combustion temperatures and reduced throttling / pumping losses to achieve thermal efficiencies in the region of 45%.

MAHLE's TJI unit replaces the conventional spark plug and can utilize the original PFI or DI fuel system in both naturally aspirated and turbocharged engines. The conventional engine control system can be retained and the system can be operated on readily available, commercial fuels. Strong synergies exist when coupling turbulent jet ignition with engine downsizing at both high and low engine loads through the use of modern variable valvetrain systems.

The ultra-high efficiency achievable with Turbulent Jet Ignition and the simplicity of the mechanical hardware and controls systems also offers unique opportunities to hybrid and range extender vehicle applications.

\*information obtained from MAHLE North America